Prepared in cooperation with the Nebraska Republican River Management Districts and the Southwest Nebraska Resource Conservation and Development Area

INTERACTION OF STREAMS AND GROUND WATER IN SELECTED TRIBUTARIES OF THE REPUBLICAN RIVER, NEBRASKA, 1998–99

BACKGROUND

The Republican River Basin occupies parts of northeast Colorado, northwest and north-central Kansas, and southwest Nebraska. The Republican River and the ground water in the underlying sand and gravel deposits occupying the river valley (alluvial aquifer) are important sources of water. Irrigation is common in many areas of the Republican River Basin, using surface water from the Republican River or its tributaries, or ground water from wells in the associated alluvial aquifers.

In 1997, the U.S. Geological Survey (USGS) entered a 4-year cooperative agreement with the Nebraska Republican River Management Districts (Lower, Middle, Upper, and Tri-Basin Natural Resources Districts (NRDs), the Frenchman Valley, Hitchcock and Red Willow, Frenchman-Cambridge, and Nebraska Bostwick Irrigation Districts), and the Southwest Nebraska Resource Conservation and Development Area to develop a regional ground-water-flow model (a mathematically based computer program that simulates ground-water flow) of the Republican River Basin upstream of the USGS streamflow station near Hardy, Nebraska (fig. 1).

A study using field measurements as indicators of the interaction of streams and ground water at selected sites along two major tributaries of the Republican River was conducted to provide supporting information for the regional ground-water-flow model. This report describes the results of that study.

STUDY AREA, DESIGN, AND FIELD METHODS

Stream/ground-water interaction was investigated at three sites in two selected tributaries of the Republican River Basin in Nebraska—Frenchman Creek near Champion, Frenchman Creek near Palisade, and Sappa Creek near Stamford (fig. 1). All three sites are located in areas containing an alluvial aquifer. Consolidated to semiconsolidated sand and gravel deposits (Ogallala Formation) form the valley walls at each site.

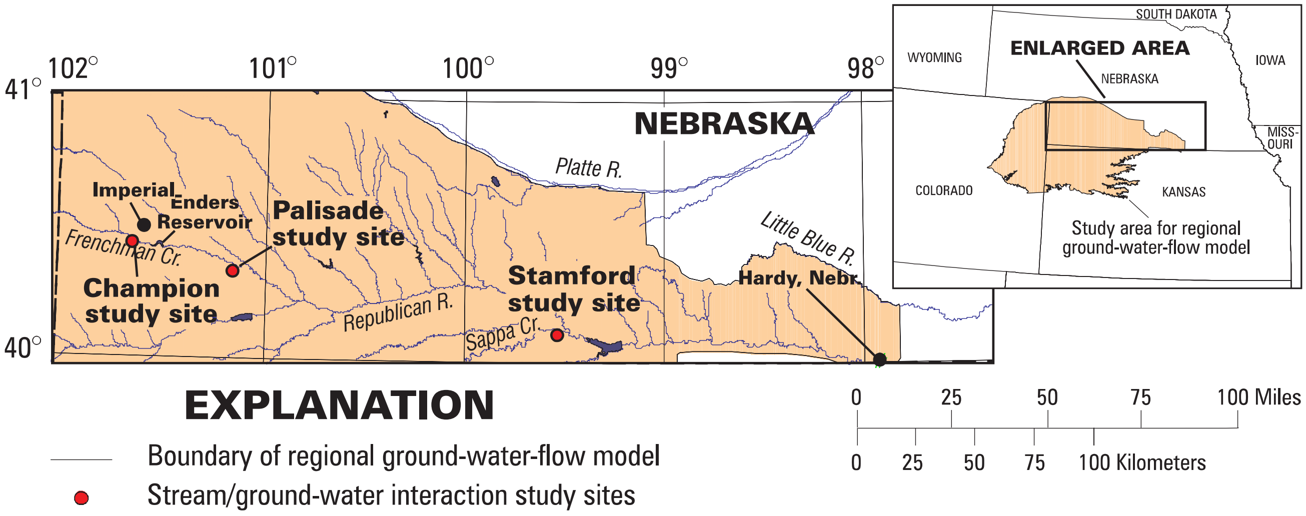

Figure 1. Regional ground-water-flow model study area and stream/ground-water interaction study sites, Republican River Basin, Nebraska, 1998–99.

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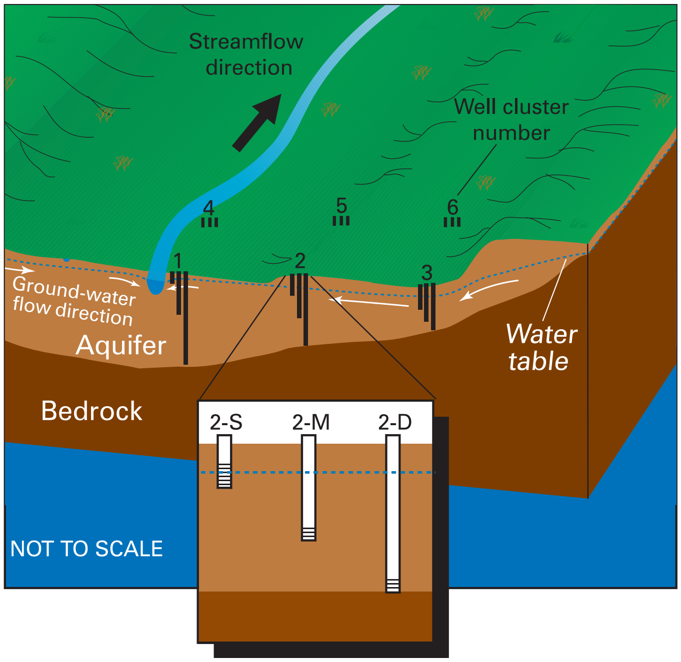

Figure 2. Schematic diagram showing orientation of monitor-well clusters with stream at the study sites (modified from Hansen, 1997).

At each site clustered monitoring wells (open to the deep, middle, and shallow parts of the aquifer) were installed in two parallel transects of three well clusters each (1, 2, 3 and 4, 5, 6), perpendicular to the stream (fig. 2). These transects ranged in length from about 800 ft (feet) at the Frenchman Creek sites to 4,000 ft at the Sappa Creek site. All wells had a screened interval of 5, 10, or 20 ft. The name of each well was determined by site, cluster numeric designation, and depth. For example, at the Champion site, the well cluster closest to Frenchman Creek in the upstream transect consists of C1-S (shallow well), C1-M (middle well), and C1-D (deep well). Except for the deep and middle wells at the Champion site, all wells were installed in the alluvial aquifer. The deep and middle wells at the Champion site were installed in the upper part of the underlying Ogallala Formation, because alluvial deposits in this part of Frenchman Creek Valley are thin and are connected hydraulically to the Ogallala Formation.

Water-level and water-quality data were collected from the wells and the stream at each site. In addition, in September 1998, data were collected using a potentiomanometer (equipment which includes the equivalent of a mini-well inserted just below the bed of the stream and a tube inserted into the stream). The potentiomanometer allows comparison of stream levels to ground-water levels just below the stream.

STREAMS

Each site is adjacent to a perennial stream (flow is year round) with a sand to silty-sand streambed. Annual mean daily flow for water year 1998 (October 1, 1997 to September 30, 1998) was 19.1 ft^3/s (cubic ft per second) at Frenchman Creek near Imperial (Nebraska Department of Water Resources, 1998) (near the Champion site), 42.3 ft^3/s at Frenchman Creek at Palisade, and 26.7 ft^3/s at Sappa Creek near Stamford (Boohar, 1999). Streamflow at each site was classified as either baseflow-dominated—Frenchman Creek—or runoff-dominated—Sappa Creek (M.K. Landon, U.S. Geological Survey, written commun., 1998). Baseflow-dominated streams get most of their flow from ground water. Runoff-dominated streams get most of their flow from overland runoff.

GROUND-WATER SYSTEMS

At each site the alluvial aquifer is unconfined and restricted in thickness and width by the underlying bedrock. In general, ground water at each site tends to flow from the valley walls toward the stream and down the valley. Depths to the water table range from less than 10 ft at the Frenchman Creek sites to as much as 30 ft at the Sappa Creek site. Wells completed in the alluvial aquifer are capable of yields of up to 1,200 gallons per minute (Steele, 1998).

STREAM AND GROUND-WATER INTERACTION

The physical characteristics of stream/ground-water interaction at each site were studied by comparing water levels measured continually in the stream to water levels measured continually in selected monitoring wells of one transect. The chemical characteristics at each site were determined by comparing values of selected chemical constituents in water samples collected from the stream to values collected from the monitoring wells. Interpretation of data for stream and ground-water interaction at each site is site specific.

Physical Characteristics

During the course of the study, three of the four common stream/ground-water interfaces described by Winter and others (1998) were observed at one or more of the sites—gaining, losing, and disconnected streams (fig. 3). Winter and others (1998) reported seasonal changes from gaining to losing or losing to gaining (fig. 3) can occur in the reaches of small streams.

To determine the direction of water flow between the stream and the aquifer, stream levels and ground-water levels were adjusted to a common base elevation (sea level). Because water flows from higher elevations to lower elevations, comparing the stream elevation to the ground-water elevation indicates which direction the water is moving. If the two systems are hydraulically connected and ground-water elevations are higher than stream elevations, ground water is moving into the stream. If the stream has a higher elevation than the ground-water elevation, water is moving from the stream into the aquifer.

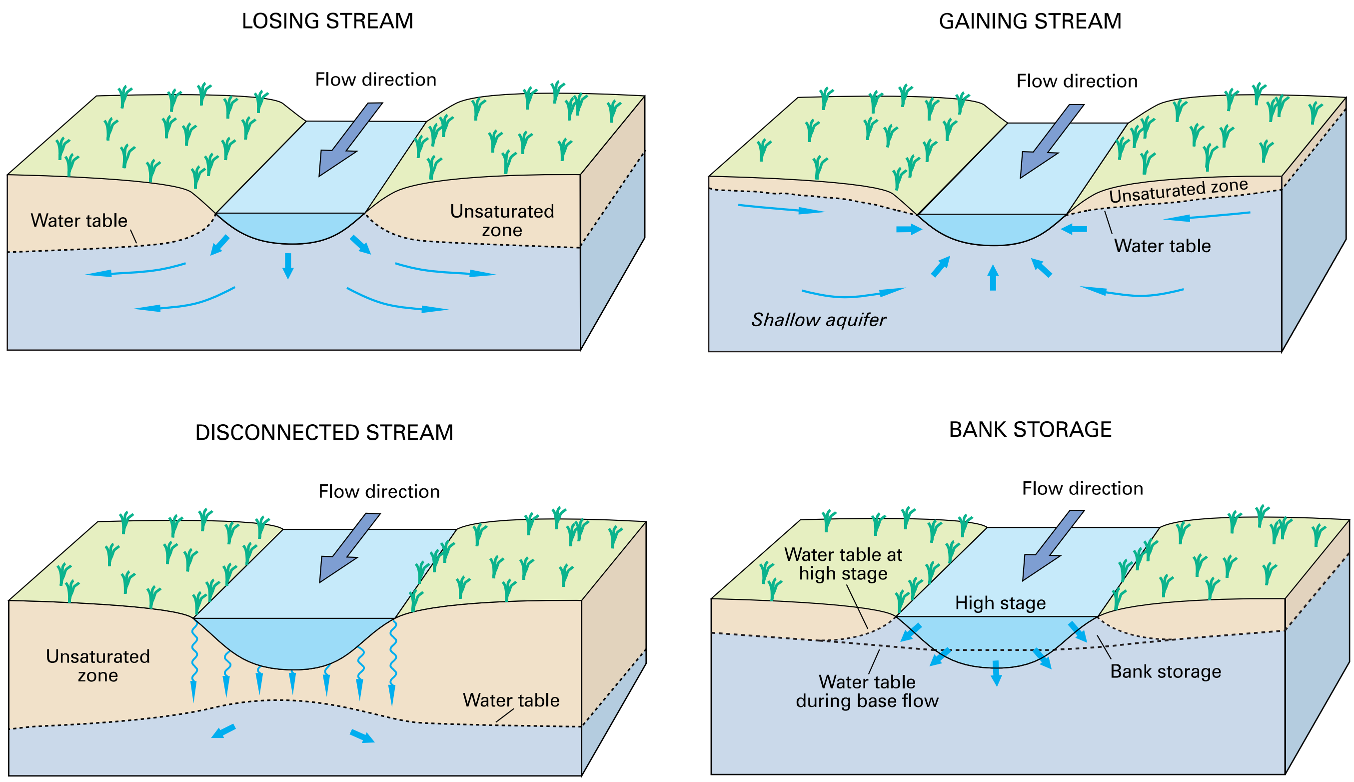

Figure 3. Schematic diagrams showing typical stream/ground-water interfaces in alluvial systems (from Winter and others, 1998).

Champion Site

Stream/ground-water interaction at the Champion site probably was affected by the presence of Light Dam 0.25 mi (mile) upstream of the site (fig. 1). Light Dam contained a shallow 29-acre reservoir whose dam was breached for renovation on July 1, 1998. Prior to the breaching of the dam, stream and ground-water levels approximately paralleled each other. However, following the breaching of Light Dam, water levels in the nearby shallow monitoring well (C1-S, fig. 4) showed increasing differences from those in Frenchman Creek. It is likely that prior to the breaching of Light Dam, reservoir water seeped through and around the dam into the ground water, and this seepage kept the ground-water levels relatively high and close to water levels of Frenchman Creek. After Light Dam was breached and the reservoir was empty, seepage from the reservoir stopped and ground-water levels responded by declining farther below the stream levels in Frenchman Creek. The difference in water levels between the stream and the ground water continued to increase until September when both levels began to rise. Ground-water levels before and after the breaching of Light Dam may have been influenced, to some extent, by pumping from irrigation wells. No irrigation wells exist in the immediate vicinity of this site, but withdrawal of ground water for irrigation typically occurs in this area during July.

Analysis of potentiomanometer data collected September 9, 1998, indicates that the water level in Frenchman Creek was 0.05 ft higher than the ground-water level directly under the stream. This suggests that Frenchman Creek was losing water to the ground-water system. During the summer months that followed the dam breaching, Frenchman Creek at this site could have fluctuated between a losing stream and a disconnected stream.

Palisade Site

Stream/ground-water interaction at the Palisade site changed during the course of the year (fig. 4). Frenchman Creek appears to have been disconnected from the alluvial aquifer until the arrival of surface water (about June 21, 1998) released from Enders Reservoir 35 mi upstream (fig. 1). Arrival of this water caused the water level of the stream at the Palisade site to rise nearly 2 ft (fig. 4). This rise allowed more surface water to infiltrate the alluvial aquifer (similar to bank storage conditions, fig. 3) and caused rises in ground-water levels of similar magnitude. Ground-water levels rose enough that the stream and ground water became hydraulically connected and the stream became a losing stream. When the releases from Enders Reservoir stopped, the water level of the stream in Frenchman Creek subsided and ground-water levels at the Palisade site returned to about pre-release elevations. Potentiomanometer data collected September 11, 1998 show that the water level in Frenchman Creek was about 1 ft higher than the ground-water level directly under the stream.

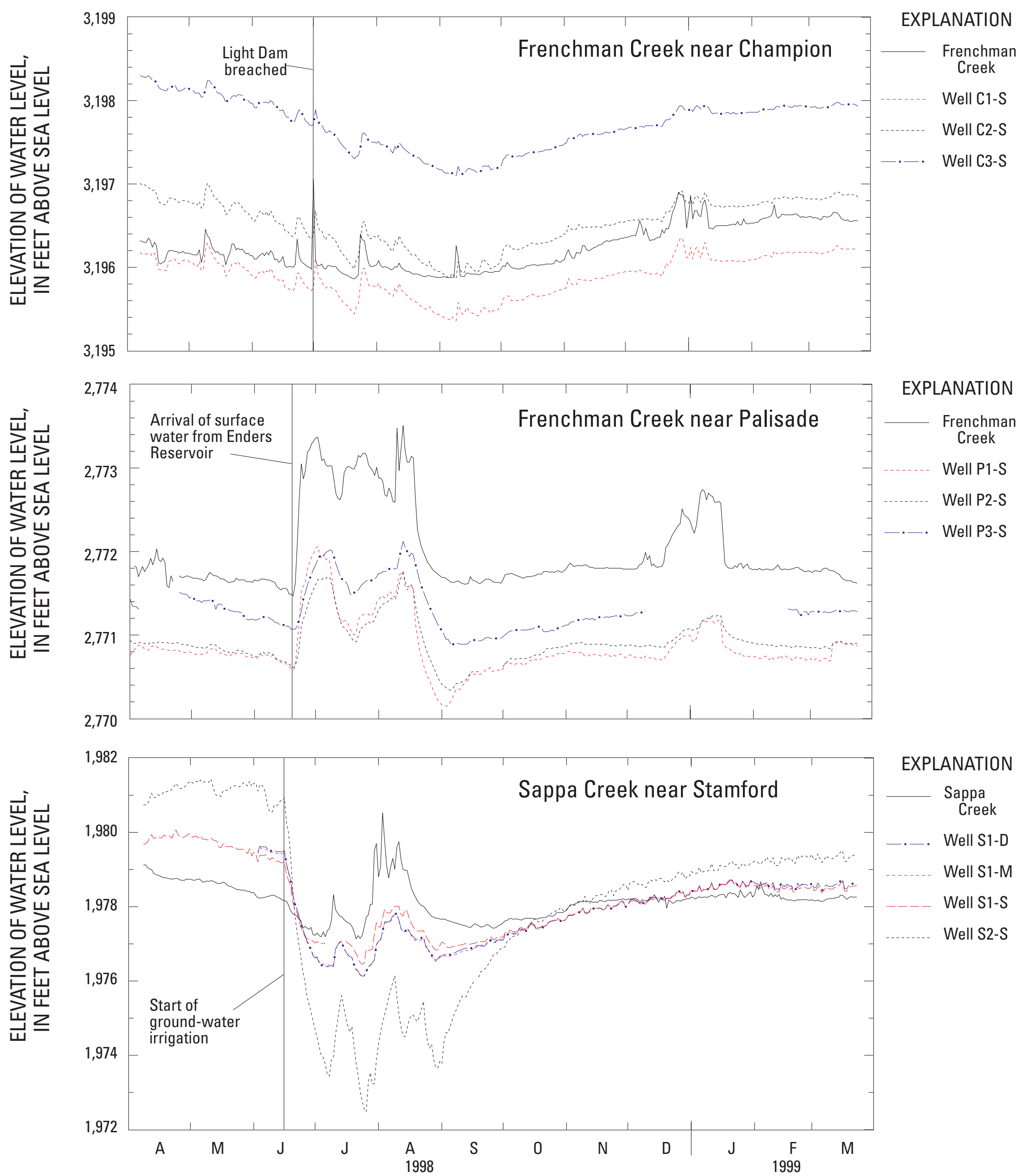

Figure 4. Hydrographs showing water levels, by site, in the stream and selected wells at the Champion, Palisade, and Stamford sites, Nebraska, 1998-99.

Stamford Site

Stream/ground-water interaction at the Stamford site changed over the course of the summer. Prior to the ground-water irrigation season (typically June to September), ground water moved toward and discharged into Sappa Creek (fig. 4). During this period, ground water also moved upward from the deep part of the alluvial aquifer through the shallow part and into the stream (fig. 4, wells S1-D, S1-M, and S1-S). Thus, at this site, Sappa Creek was a gaining stream prior to ground-water irrigation. During the irrigation season, withdrawals of ground water by nearby irrigation wells resulted in declining ground-water levels (fig. 4, well S2-S), and ground-water-flow directions shifted toward the lowest ground-water levels. The vertical ground-water-flow directions started moving toward the lowest ground-water levels. The vertical ground-water-flow component reversed, resulting in flow from the shallow to the deep parts of the alluvial aquifer. During these changes in ground-water-flow direction, water from the stream likely infiltrated the alluvial aquifer, resulting in a change from a gaining to a losing stream. Following the end of ground-water withdrawals, the alluvial aquifer at this site returned to pre-irrigation season conditions and Sappa Creek again became a gaining stream.

Chemical Characteristics

Chemical characteristics of the streams and ground-water were studied by collecting water samples in April, August, September, and October 1998, and March 1999. Field measurements (specific conductance, pH, water temperature, and dissolved oxygen) were collected on site. Water samples collected for nitrate as nitrogen, and major ions (collected in August 1998)—including calcium, magnesium, sodium, chloride, fluoride, and sulfate—were analyzed at the USGS National Water Quality Laboratory in Lakewood, Colorado. In addition, water samples were collected in September 1998 from selected wells and analyzed for chlorofluorocarbons (CFCs) at the USGS Reston Chlorofluorocarbon Laboratory in Reston, Virginia. CFC samples were used to estimate when the water entered the aquifer (recharge date) using methods described by Busenberg and Plummer (1992).

The greatest differences in chemical characteristics between the streams and ground water of the three sites occurred at Sappa Creek (table 1). In August (during irrigation season) the specific conductance value in the ground-water sample from the shallow well adjacent to Sappa Creek (686 µS/cm (micro-seimens per centimeter)) was nearly half the values measured in April (1,220 µS/cm) (pre-irrigation season) and October (1,160 µS/cm) (post-irrigation season) and closer to the stream value in August (338 µS/cm). Specific conductance values at the Frenchman Creek sites did not change substantially during the course of the study. Ground-water temperature at all three sites was greatest nearest the stream and smaller away from the stream.

Except for the Stamford site, no substantial differences in nitrate concentrations between stream and ground-water samples occurred. At the Stamford site, the nitrate concentrations in the sample from the shallow well adjacent to Sappa Creek was greatest during the irrigation season (1.32 mg/L (milligrams per liter)) and similar to the value in the sample from Sappa Creek (1.07 mg/L) that was collected at the same time.

Table 1. Median values of field measurements and nitrate concentrations from water samples collected in streams and monitoring wells at the Champion, Palisade, and Stamford sites, Nebraska, 1998-99

[µS/cm, microseimens per centimeter at 25 degrees Celsius; ^{o}C, degrees Celsius; mg/L, milligrams per liter; <, less than]

Site	Number of samples	Specific conductance (µS/cm)	pH (standard units)	Water temper-ature (^{o}C)	Dissolved oxygen (mg/L)	Nitrate as N (mg/L)
Frenchman Creek near Champion	5	449	8.5	13.0	10.8	1.71
Champion well clusters	40	493	7.5	13.5	2.0	1.40
Frenchman Creek near Palisade	5	445	8.7	19.5	11.6	.76
Palisade well clusters	40	444	7.7	13.5	1.4	1.70
Sappa Creek near Stamford	5	980	8.4	14.0	13.1	.57
Stamford well clusters	45	1,210	7.2	14.0	.4	<0.05

Table 2. Estimated recharge date from chlorofluorocarbon analyses of water samples collected at the Champion, Palisade, and Stamford sites, Nebraska, 1998

[S, shallow well; M, middle well; D, deep well; --, sample not collected, <, before date listed; Note: date indicates that a component of the water sample contained water of that age; sample also can contain younger water than indicated. Example: Stamford well-cluster 4S also contained recent water (from specific conductance values and nitrate concentrations)]

	Adjacent to stream (well-cluster 4)			Middle cluster (well-cluster 5)			Adjacent to valley wall (well-cluster 6)		
Site	S	M	D	S	M	D	S	M	D
Champion	Mid 1940s	--	<1940	--	--	--	Late 1960s	--	Mid 1960s
Palisade	Late 1970s	--	Mid 1970s	--	--	--	Mid 1980s	--	Mid 1960s
Stamford	Mid 1960s	Early 1960s	Early 1960s	Early 1980s	Early 1980s	Late 1960s	Late 1990s	Mid 1970s	Late 1970s

The results of the specific conductance values and the nitrate concentrations suggest that some water from Sappa Creek is entering the ground water during the irrigation season. Other chemical analyses were inconclusive as tools used to determine stream/ground-water interaction at the sites. Analysis of CFC data indicates that the ground water is progressively older from the valley wall to the stream (table 2). This confirms that, in the long term, ground water predominantly moves from the valley walls toward the stream.

CONCLUSION

Stream/ground-water interaction at the study sites on the tributaries of the Republican River was highly variable, indicating interactions are likely to be influenced by many local factors. In addition, the connection between the stream and ground water at the three sites changed during the course of the year.

At the two Frenchman Creek sites, the stream was losing water to the ground-water system or the stream was disconnected from ground-water system and remained a losing stream throughout most of the year. The Champion site was predominantly a losing stream after the breaching of Light Dam upstream. Although data were inconclusive, Frenchman Creek at the Champion site may have fluctuated between a losing stream and a disconnected stream following the breaching of Light Dam. At the Palisade site, following release of surface water upstream, infiltration of surface water changed Frenchman Creek from a disconnected stream to a losing stream. When surface-water releases stopped, Frenchman Creek at this site returned to about pre-release conditions.

At the Sappa Creek site, the stream was a gaining stream throughout the non-irrigation season. When ground-water irrigation began, ground-water levels declined, ground-water-flow directions reversed, and Sappa Creek became a losing stream. Sappa Creek returned to a gaining stream after the irrigation season.

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—By G.V. Steele

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